Surgical treatment of femoral fractures in children

Comparison between external fixation and elastic intramedullary nails: A review

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Submitted 04-01-08. Accepted 04-02-28

ABSTRACT **Femoral fractures represent about 2% of all fractures in childhood. Children with femoral fractures always need to be admitted to hospital and the use of resources is much higher than for other childhood fractures. During the past decade, there has been a trend towards surgical treatment of these fractures, one advantage being the shorter time required in hospital. Two common surgical treatment options are external fixation (EF) and elastic stable intramedullary nails (ESIN). Both methods have their advantages and disadvantages, and neither of them solves all of the problems. Used in a complementary manner, they are safe and reliable for the treatment of femoral fractures in children, and they give good long-term results and few serious complications.**

Femoral shaft fractures comprise 2% of all fractures in children and adolescents. The fractures are more common the younger the child is (Nafei et al. 1992). A small child can sustain a fracture by a simple fall on level ground while playing, but for the older child a stronger force is required (Hedlund and Lindgren 1986, Landin 1986, Hinton et al. 1999). Most fractures are displaced and factors that should be considered for choice of treatment are age, type of injury, associated injuries, type and location of the fracture, psychological and social situation and the ability of the family to take care of the child.

For many years, conservative treatment with traction and/or casting has been the gold standard for all femoral fractures in children, with relatively good results. The disadvantages are that the child is tied to the bed with traction or to a wheelchair with spica cast, that there is pain during nursing, that there is a risk of skin problems, and that repeated radiographs are required because of difficulties in maintaining the alignment. For parents, the treatment may result in a long period away from work and for the child there may be a long absence from school. It has become more common for parents not to want a prolonged treatment time in traction for their children. In many societies, the economic pressure to reduce health care costs also favors treatments that reduce hospitalization time (Newton and Mubarak 1994, Blasier et al. 1997, Boman et al. 1998, Stans et al. 1999).

During the last decade, there has been a trend toward surgical management and early mobilization of children with femoral fractures. There are several methods, and there is no consensus about which is best, especially in children less than 12 years of age. The main arguments against surgical treatment are fear of complications which differ from those seen after traction and cast.

Surgical methods that have become less common

To achieve early mobilization, methods used for adult fractures have been tested on children. One of these is intramedullary rigid nailing (reamed or non-reamed) with or without interlocking screws, indicated for adolescents with femoral fractures that are difficult to manage in traction (Galpin et al. 1994). Complications are myositis ossificans at the entrance of the rod, premature closure of the greater trochanteric physis with a risk of increased femoral neck valgus, avascular necrosis of the capital femoral epiphysis because of the type of blood distribution to the femoral head, leg length discrepancy, and neurological problems, with decreased sensation in the distribution of the peroneal nerve (Chung 1976, Raney et al. 1993, Beaty et al. 1994, Galpin et al. 1994, Mileski et al. 1994, O'Malley et al. 1995, Letts et al. 2002).

The other option is open reduction and internal fixation with plates and screws. Both interfragmentary compression and a dynamic compression technique can be used (Ward et al. 1992). Indication for this treatment has been children aged 6–11 years (Levy and Ward 1993) with head injuries with agitation and spasticity or with multiple injuries (Kregor et al. 1993). The treatment allows anatomic reduction, simplified nursing, and rapid mobilization, and can be applied to any size of femoral shaft. Most surgeons are familiar with the procedure. The disadvantage is the need for two major operations and the fact that the patient can be allowed only partial weight bearing until healing is seen on radiographs (Sponseller 2002). In recent years, plate osteosynthesis with a minimal invasive technique has been introduced (van Riet et al. 1996, Schütz et al. 2001, Bellabarba et al. 2002). Known complications of plate fixation are infection, fracture below the plate, stress fractures, refractures, overgrowth both after the first operation and after plate removal, hardware failure with plate breakage, hypertrophic scars, and in some cases the need for blood transfusions (Levy and Ward 1993, Fyodorov et al. 1999, Mostafa et al. 2001, Sponseller 2002).

Although the incidence of complications after nailing or plating is below 10%, some of the complications are serious and have made orthopedic surgeons choose other treatment options and reserve these procedures for special cases only.

Surgical methods that have become increasingly more common

1. Elastic stable intramedullary nails (ESIN). For many years, different kinds of elastic intramedullary nails have been used. Hackethal (1963) reported satisfactory results when fixating femoral shaft fractures in children using multiple thick (2–3 mm) Kirschner wires percutaneously and retrograde. Rush pins have been used in femoral fractures in children with good results, especially in children with severe brain trauma or multitrauma (Viljanto et al. 1975, Ziv and Rang 1983, Ziv et al. 1984). Ender nails, first introduced for trochanteric fractures in adults, were also used in the 1980s in femoral shaft fractures of brain-injured, hyperkinetic, or polytraumatized older children (Herndon et al. 1989, Kissel and Miller 1989, Heinrich et al. 1992). Depending on the location of the fracture, antegrade or retrograde insertion can be used. In the 1990s, the Ender nails were used in ages from 3–18 years (Heinrich et al. 1994, Linhart and Roposch 1999), even with interlocking (Linhart and Roposch 1999), and with good results.

Figure 1. Elastic stable intramedullary nails used in transverse fracture.

At the end of the 1980s and the beginning of the 1990s, new types of nails were introduced: flexible stable nails in titanium from the Nancy group (Ligier et al. 1988) and the C-nails from the AO group (Flynn et al. 2001) (Figure 1). Titanium is thought to give higher flexural elasticity (Schlickewei and Salm 2001), imitating the mechanics of the bone. Ender nails are not sufficiently elastic for children (Ligier et al. 1988); the stainless steel is 80% stiffer than the titanium in the nails (Flynn et al. 2001). The elasticity of titanium limits the extent to which the nail can be permanently deformed during insertion, but at the same time it promotes callus formation (Flynn et al. 2001). The operative technique is important and requires balancing of the forces of the two opposing flexible nails with six-point stability (Ligier et al. 1988, Mazda et al. 1997). A fracture table can be used (Ligier et al. 1988), but some surgeons prefer to have the patient in a supine position without traction (Houshian et al. 2004). The nail diameter is chosen as 40% of the isthmus of the femoral shaft. The nail should be precurved before insertion. Recently, it has been shown that the mechanical properties are the same whether the nails are C- or S-shaped (Kiely 2002). The apex of the nails should be at the fracture site and they should be inserted at the same level in the metaphysis to prevent residual angulation (Ligier et al. 1988). In most cases, the nails are used retrograde with one nail from the lateral and one from the medial side inserted just above the growth cartilage. With distal fractures, the nails can be inserted antegrade just below the greater trochanteric physis by a single lateral approach although the six-point stability is best obtained with retrograde nailing (Mazda et al. 1997). To avoid soft tissue irritation, only a small part of the nail should be left outside the distal metaphyseal cortex, but at the same time this should be enough to allow easy removal. Full weight bearing is usually not recommended by most authors until the fracture has healed (Sponseller 2002). This is especially important with comminuted and long spiral fractures, and when the child weighs more than 45 kg (Roposch and Linhart 2002).

2. *External fixation (EF)*. The use of external fixation in children was described as early as 1929 by Ombrédanne (1929), who used temporary external fixation in all kinds of fractures in children, including femoral fractures. The fixator was exchanged for a cast. Haynes (1943) described external fixation of a femoral fracture in a preschool child. In a historic review, Sisk (1983) stated that for the past two centuries external fixation has enjoyed long periods of enthusiastic use alternating with intervals of total disrepute. The reason is probably that external fixation is a quick

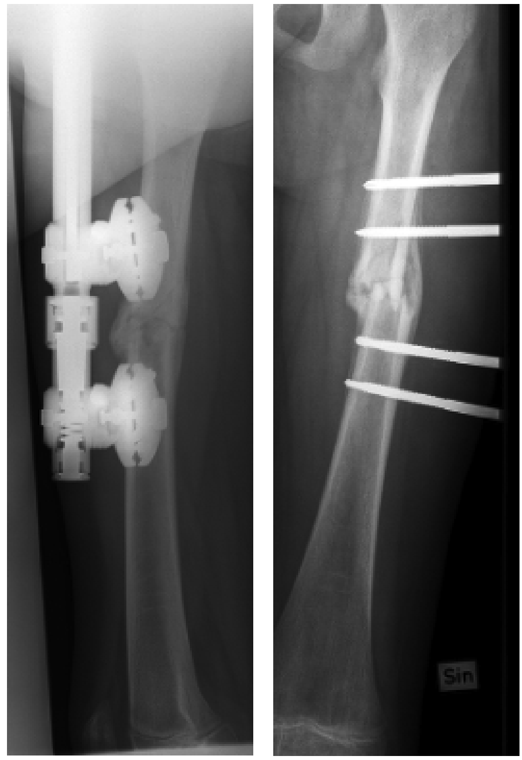

Figure 2. External fixation with Monotube system used in transverse fracture. Note 2 briding cortices in lateral and frontal views.

method for treating fractures without exposing the fracture itself, but that several complications may occur. Some authors have stated that external fixation should only be used in open fractures or in patients with multitrauma (Alonso et al. 1989, Kirschenbaum et al. 1990, Krettek et al. 1991, van Tets and van der Werken 1991, Gregory et al. 1996). Other authors have advocated general use of external fixators when treating femoral fractures in children, as the advantages were found to be greater than the disadvantages of the complications (Aronson and Tursky 1992, Evanoff et al. 1993, Blasier et al. 1997, Skaggs et al. 1999, Hedin et al. 2003) (Figure 2).

Even with external fixation, the operative technique is important. There are different kinds of external device. The fixator should have maximum versatility with a minimum number of parts to facilitate application, a single bar system which controls lateral bending and torque forces while permitting dynamic axial loading once callus formation begins (De Bastiani et al. 1984). A

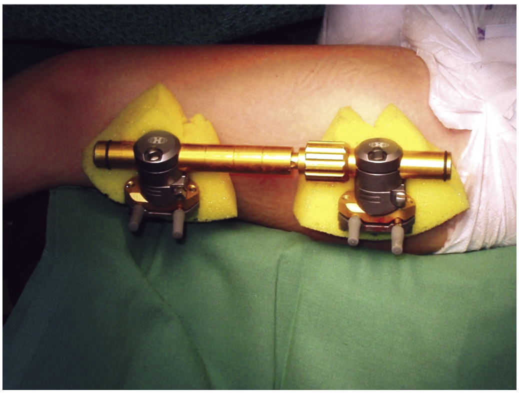

Figure 3. Sponges used as dressing round pins in external fixation to minimize infection.

Appearance just before removal of pins.

relatively small unilateral frame can be as stable as a larger three-dimensional one (Chao et al. 1988, Broekhuizen et al. 1990). The fixator should be light and without bulky parts in order to allow the child to function as normally as possible. In children, the weight of the fixator is as important as the rigidity (Alonso and Horowitz 1987). The healing time will be prolonged if the fixator is too rigid (Kaelin et al. 1990, Weinberg et al. 1994). One of the most important parts in an external fixator system is the pin-bone interface (Hyldahl et al. 1991). Any type of preparation of the bone, regardless of the instrument or the cutting method used, seems to be harmful to the bone. The critical temperature for bone morphological changes can be as low as 47 °C, a temperature which is exceeded in most pin insertions (Wilkenheiser et al. 1995). Thus, it is important to use a manual or slow-speed drill when inserting the pins. Although a 6 half-pin configuration is stiffer (Chao et al. 1988), the stiffness of a 4 half-pin configuration is sufficient for fractures in children where less rigidity promotes callus formation (Hull et al. 1997). The maximum deflection has been observed to occur at the fracture site. The two pins on either side of the fracture gap should therefore be as close to the fractured end as possible, but at least 2 cm away to avoid the fracture hematoma (Oni et al. 1993). The pin clamps should be close to the skin, but at a distance with no risk of pressure to the skin, as some swelling can always be expected. For the remaining pins, the ideal solution would be to place them as far away from the first pins as possible, but the distance in the clamps sets a limit for how far away the pins can be placed. Full weight bearing can be allowed as soon as the child wants it, irrespective of age, fracture level or fracture type (Hedin et al. 2003).

Pin site care can be nihilistic, with no local cleaning except for what takes place during daily showers begun postoperatively on day 5 (Gordon et al. 2000). Dressing should be minimal and foam rubber sponges can be used (Figure 3). Oral antibiotics can be given for a short period if there are signs of inflammation around the pins (Hedin et al. 2003). The fixator can be removed when the fracture is clinically stable (fully pain-free weight bearing, and stable when tested without the fixator with the pins still in place) and the radiographs show bridging callus formation in at least three out of four cortices shown on the radiographs in the lateral and anterior-posterior view (Skaggs et al. 1999).

Comparison between elastic stable intramedullary nails (ESIN) and external fixation (EF)

To my knowledge, the paper by Bar-on et al. (1997) is the only randomized study on external fixation and flexible intramedullary nailing for femoral shaft fractures in children. However, there were only 19 children with 20 fractures in the study and 10 fractures in each group. None of the groups were homogenous concerning fracture type, time interval to surgery, kind of fixator or nail, mode of insertion of nails, or use of fracture table. Parents were allowed to choose between surgical and nonsurgical treatment. There was no indication as to whether any of the parents chose nonsurgical treatment. In each group the fractures were treated in different ways, so it is difficult to interpret and compare the results.

I have therefore based my comparison on retrospective and prospective studies of each of the methods (Tables 1 and 2).

Age

The lower age limit for treating children with femoral fractures operatively has been set to 6 years. This limit is arbitrary (de Sanctis et al. 1996) and, as can be seen in Tables 1 and 2, the lower limit can be around 3 years with the same good results. For elastic nails, it is the diameter of the nails and the intramedullary canal that set the limits. The external fixator can be used in very small children, but it is usually considered when the child is too heavy for skin traction, which is around 3 years of age. The external fixator can be used instead of inserting a pin for traction or using a spica cast (Hedin et al. 2003).

Fracture type

Both ESIN and EF can be used in all kinds of fractures. With long spiral and comminuted fractures, there is risk of dislocation and shortening of the fracture and nail migration with ESIN (Heinrich et al. 1994). Both ESIN and EF can be used in open fractures of grade I (Gustilo and Anderson 1976). Grade II and III fractures can be treated with EF, but these are rare in children.

Location of fractures

Very proximal or distal fractures are difficult to treat with ESIN because of the risk of disturbing the growth plate (Raney et al. 1993) and the risk of avascular necrosis of the femoral head (Mileski et al. 1994). EF can be used from the inferior edge of the lesser trochanter to 2 cm proximal to the distal femoral physis (Hedin et al. 2003).

Associated injuries

Many of the children have associated injuries, which makes it difficult to treat them in traction or cast. This is especially the case with brain damage. Both ESIN and EF are superior for treating these children. With bilateral femoral fractures, there appears to be a higher risk of refracture when using EF (Miner and Carroll 2000, Hedin et al. 2003).

Learning curve

With every surgical procedure, there is a learning curve. Both ESIN and EF are procedures that most orthopedic surgeons are familiar with from treating adults, and the learning curve is shallow (Weinberg et al. 1994, Cramer et al. 2000, Hedin et al. 2003).

Psychological and social considerations

Only a few authors have addressed the psychological effects of different treatments for children (van Tets and van der Werken 1991, Hughes et al. 1995, Stans et al. 1999). We do not know the long-term effect of treatment in traction (Hughes et al. 1995). Treatments that can minimize days in hospital and days of absence from school for the children and time away from work for the parents minimize the burden for the family and for society in general (Reeves et al. 1990, Newton and Mubarak 1994, Blasier et al. 1997, Hedin et al. 2003, 2004).

Complications

The most common complication for ESIN is pin migration, with skin irritation distally and sometimes infection (Table 1).

For EF, the most common complication is infection or inflammation at the site of the pin. Infection is related to the treatment time. The infections are mild and resolve with a short period of oral antibiotics (Table 2).

Refractures occur with both treatments and are mostly due to technical errors (Ligier et al. 1988, Weinberg et al. 1994) or premature nail and fixator removal (Ligier et al. 1988, Weinberg et al. 1994). To minimize this risk, the fracture should have bridging callus in three cortices seen in the radiographs on lateral and anterior-posterior view, before removal is considered (Skaggs et al. 1999) (Figure 2). Bending after removal, reported for EF (Aronson and Tursky 1992, Hedin et al. 2003) and known from leg lengthening, is also due to premature removal of the fixator.

Malunion, both rotational and angular, are minimal in both methods and are prone to remodeling during growth. Rotational malunions in particular can be avoided by using a traction table during operation (Hedin et al. 2003).

Overgrowth or shortening of the fractured leg is less than expected for both methods and within a limit of ± 10 mm, affording the possibility of

Table 1. Reports on elastic stable intramedullary nails (ESIN) for treatment of femoral fractures in children

A	B	C	D	E	F	G	H	I
Ligier et al. 1988	118/123	5–16	a, b		123	na	4. 5	Spica cast 4, traction 5, skin ulceration 13, deep infection 1, reoperation 13 (for trimming or exchange of nails)
Kissel et al. 1989	14/14	8–13	a		14	90	8	Malunion 1; all had spica cast
Heinrich et al. 1994	77/78	2.9–18	a		64	86 (50–140)	8 (2–25)	Reoperation 4, refracture 1, fracture collapse 2, pain distally 1
Mazda et al. 1997	32/34	6–17	b		29	96 (50–240)	11 (3–28)	Malalignment 4, leg length discrepancy > 10 mm 3, irritation distal with bursa 10
Buess et al. 1998	43/43	2.6–13.6	b		43	na	9.2	Skin irritation distally 14, reoperation 10, > 15° external rotatation 5, proximal perforation of nail 1, bowing of nail 1, refracture 1
Linhart el al. 1999	17/17	2.5–15	a	+	17	na	8	Irritation dist. 1, overgrowth 1.5 cm 1, weather sensitivity 2
Cramer et al. 2000	52/57	5–14	a	+	57	na	na	10–15° malalignment 4, increased comminution during surgery 5, skin irritation distally 3, breakage of locking screw 2, hematoma after nail removal 1
Flynn et al. 2001	57/58	4–16	b		58	na	na	5–10° malalignment 6, 1–2 cm leg length discrepancy 6, refracture 1, backout of nail 1, 20° varus malalignment 1, irritation by prominent nail 4, deep infection 2
Buechsenschuetz et al. 2002	42/42	5.3–14.11	b		42	11–60	4.6	Pin migration through skin 6, pain 1, reop. 1, pulmonary embolism 1, malunion 9
Houshian et al. 2003	31/31	4–11	b		31	60 (40–100)	6 (2–20)	perforation of nail dist. 1, internal rotation of 10° 1

A Series
B Number of patients/fractures
C Age, years
D Nails
  a Ender
  b Titanium
E Locking screws
F Retrograde
G Operation time, min
H Hospital stay, days
I Complications

anatomic reduction without overlap, as has been recommended earlier (Shapiro 1981, Tachdjian 1990).

There will be scars with all surgical procedures, even with pin traction (Buechsenschuetz et al. 2002). With EF, the scars will be on the lateral side of the thigh and with ESIN they will be on both sides of the knee, and a little further. In both cases, the appearance of the scars depends on whether an infection has occurred or not. Complications are

Table 2. Reports on external fixation (EF) for treatment of femoral fractures in children

A	B	C	D	E	F	G	H
Kretek et al. 1991	16/16	7–16	a	63 (41–100)	na	na	Pin site infect./inflam. 4
Aronson et al. 1992	42/44	2.5–17.8	a, b, f	70 (42–117)	na	7.4	Pin site infect./inflam. 15, > 5° varus 6, > 5° valgus 2, bending after removal 2
Weinberg et al. 1994	59/59	4–13	a, b, e	57 (35–80)	na	na	Pin site infect./inflam. 3, disl. due to technical problems 4, refracture 2
Gregory et al. 1996	27/27	5.6–13.2	a, b	(37–109)	na	4.2	Pin site infect./inflam. 14, refracture 2, fracture through pin hole 2
de Sanctis et al. 1996	81/82	6–13	d	60 (33–114)	na	7.3	Pin site infect./inflam. 7, > 10°angulation 6
Blasier et al. 1997	132/139	2–15	a, b, f	81 (35–154)	na	6.9	Pin site infect./inflam. 50, reoperation 2, > 12° valgus 1, > 30° rotation 1, refracture 2, fracture through pin hole 1, myositis ossificans 2
Sola et al. 1999	37/39	5.11–18.8	b	97 (50–175)	na	9	Pin site infect./inflam. 16, refracture 1,
Skaggs et al. 1999	66/66	4–14	a, b, c	79 (28–168)	na	na	Pin site infect./inflam. 37, refracture 5, fracture through pin hole 3
Miner et al. 2000	33/37	4–14	a, c	107 (61–149)	na	na	Pin site infect./inflam. 24, refracture 8 in 4 bilateral fractures
Hedin et al. 2003	96/98	3–15	e	61 (37–127)	50 (20–135)	8.7	Pin site infect./inflam. 36, refracture 1, fracture through pin hole 1, myositis ossificans 1, bending after removal 3

A Series
B Number of patients/fractures
C Age, years
D Fixators
 a AO
 b Orthofix
 c EBI
 d Ex–Fl–Re
 e Monotube
 f Wagner
E Treatment time, days
F Operation time, min
G Hospital stay, days
H Complications

more frequent in children with multitrauma and with associated injuries (Schmittenbecher 2001).

In summary, both methods have advantages and disadvantages (Table 3). Probably there is no single method that solves all problems, and it is useful to be familiar with both ESIN and EF. A treatment algorithm is proposed here (Table 4), which is based on known studies.

Conclusion

Both elastic stable intramedullary nails and external fixation appear to be safe and reliable methods that have good long-term results in the treatment of femoral fractures in children aged 3–15 years. Both methods have advantages and disadvantages, but the overall results make them superior to both traction and cast – even for treatment of isolated femoral fractures in children. For social, psychological and economic reasons, it is time to abandon traction and cast as treatments for femoral fractures in children, as was done long ago for femoral fractures in adults. Now, when the long-term results are as least as good or even better after a surgical treatment option, the choice is easy.

Table 3. Comparison of advantages and disadvantages of elastic stable intramedullary nails and external fixation in treating femoral fractures in children

Method	Advantages	Disadvantages
Elastic stable intramedullary nail		
	minimally invasive	risk of infection at nail tip
	fracture site need not be opened	nail migration
	can be used in grade I open fractures	the need for a second operation for nail removal
	acts as internal load sharing splint	can be difficult to remove
	physis can be avoided	risk of refracture at premature nail removal
	early mobilization	not stable in long spiral or comminuted fractures
	relatively early weight bearing	does not tolerate full weigth bearing the first weeks
	fewer radiographs needed	not stable enough in children > 45 kg
	short hospitalization	knee pain
	lower risk of growth disturbances	cannot be used in very distal or proximal fractures
	malunions minimal	stiffness in knee
	short learning curve	scars
External fixation		
	minimally invasive	risk of pin site infection/inflammation
	can be used in all fractures	risk of refracture at premature fixator removal
	fracture site need not be opened	risk of bending at premature fixator removal
	can be used in all open fractures	stiffness in knee
	physis can be avoided	risk of delayed union in transverse fractures
	no disturbance of blood supply to femoral head	“bulky parts” outside the leg
	early mobilization	scars
	immediate weight bearing	
	fewer radiographs needed	
	short hospitalization	
	lower risk of growth disturbances	
	malunions minimal	
	short learning curve	
	easy to apply and remove	

Table 4. Treatment protocol for femoral fractures in children

Age	Fracture	Treatment option
< 3		Skin traction 1 week followed by spica cast or immediate spica cast
3–15	Transverse fractures	Elastic stable intramedullary nails
	Short oblique fractures	Elastic stable intramedullary nails or external fixation
	Long spiral or comminuted fractures	External fixation
	Grade II and II open fractures	External fixation
> 12		Rigid intramedullary nails can be considered

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